Siri Duddella

PHYS265

Dr. Clark and Dr. Teuben

May 6, 2025

Lab 3: ATLAS Data Analysis

I Introduction

The ATLAS (A Toroidal Large Hadron Collider Apparatus) experiment at CERN in Geneva, Switzerland focuses on smashing together high energy protons that are smashed together, resulting in byproducts that can be studied. Primarily, we focus on studying the mass of the Z^0 boson, a product of protein-protein interactions in the LHC. The Z^0 boson is unstable and decays into a pair of charged leptons about 10% of the time. The sum of the two leptons has to equal the mass of Z^0 particles due to conservation of matter and energy. This means that measuring the energy of the l^+l^- events in the detector would result in being able to see an excess or a peak at the mass of the Z^0.

In this report, first, I analyzed a dataset of 5000 proton-proton collisions to compute the invariant mass M of each lepton pair and develop a histogram from the data. Then, I used a Breit-Wigner curve fit to find the mass and width of the Z^0 boson and study the $\Delta\chi^2$/NDOF, and p-value in the fitting range. Finally, I did a 2D chi-square scan of the mass-width parameter space, since this is a 2D fit, and create a filled contour plot of $\Delta\chi^2$ values clipped at 35 units, with the 1 σ and the 3 σ confidence intervals.

II The Invariant Mass Destribution and Fit

(1) $p_x = p_t cos(\phi)$, $p_y = p_t sin(\phi)$, $p_z = p_t sinh(\phi)$

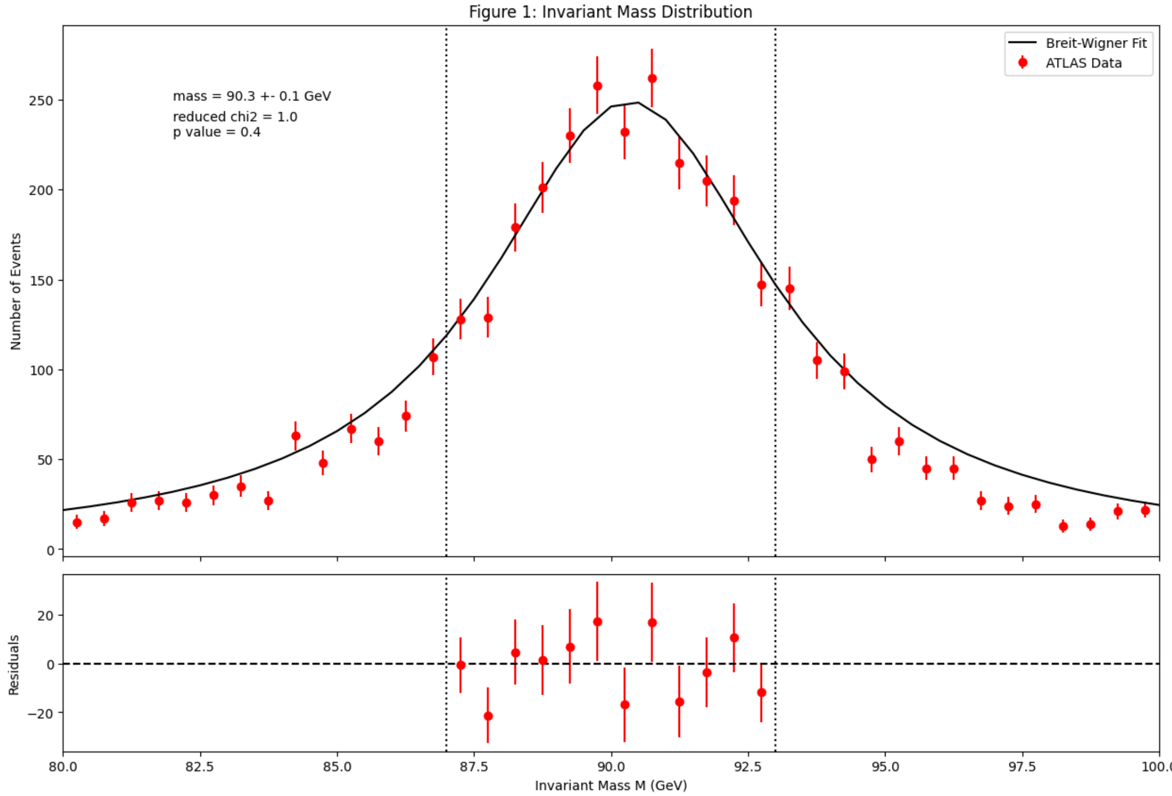
(2) $M = \sqrt{E^2 - ((p_x)^2 + (p_y)^2 + (p_z)^2)}$

First, I used the 5000 values from the real 2020 ATLAS dataset that only contain final states with two leptons. I loaded the data into Python using Pandas and calculated the three momentums using Equation 1. Then, I calculated the mass of the hypothetical particle which decayed to produce the pair using Equation 2. From the mass data, I created a histogram with error bars of the calculated invariant mass, approximating the data as a Poisson counting experiment using a range of 80 to 100 GeV with 41 bins.

(3) $D(m; m_0; \Gamma) = \frac{1}{\pi} \frac{\Gamma/2}{(m-m_0)^2+(\Gamma/2)^2}$

In Part 2, I coded a function that returns the decay distribution (Equation 3) and fit the mass-distribution with the Breit-Wigner function. Then I fitted the data such that it's normalized with half the data and the bin centers are 87 < x < 93 GeV only with the same 41 bins, and plot it with residuals in the second plot (Figure 1). Next, I calculated the chi-square (10.0), reduced-chi-square with NDOF = 10 (1.0), and p-value (0.4) in the fitting range and calculate the best fit mass, m_0 (90.3 GeV), and its uncertainty (0.1 GeV). The reduced chi-square value and p-values confirm that the fit is good for the data.

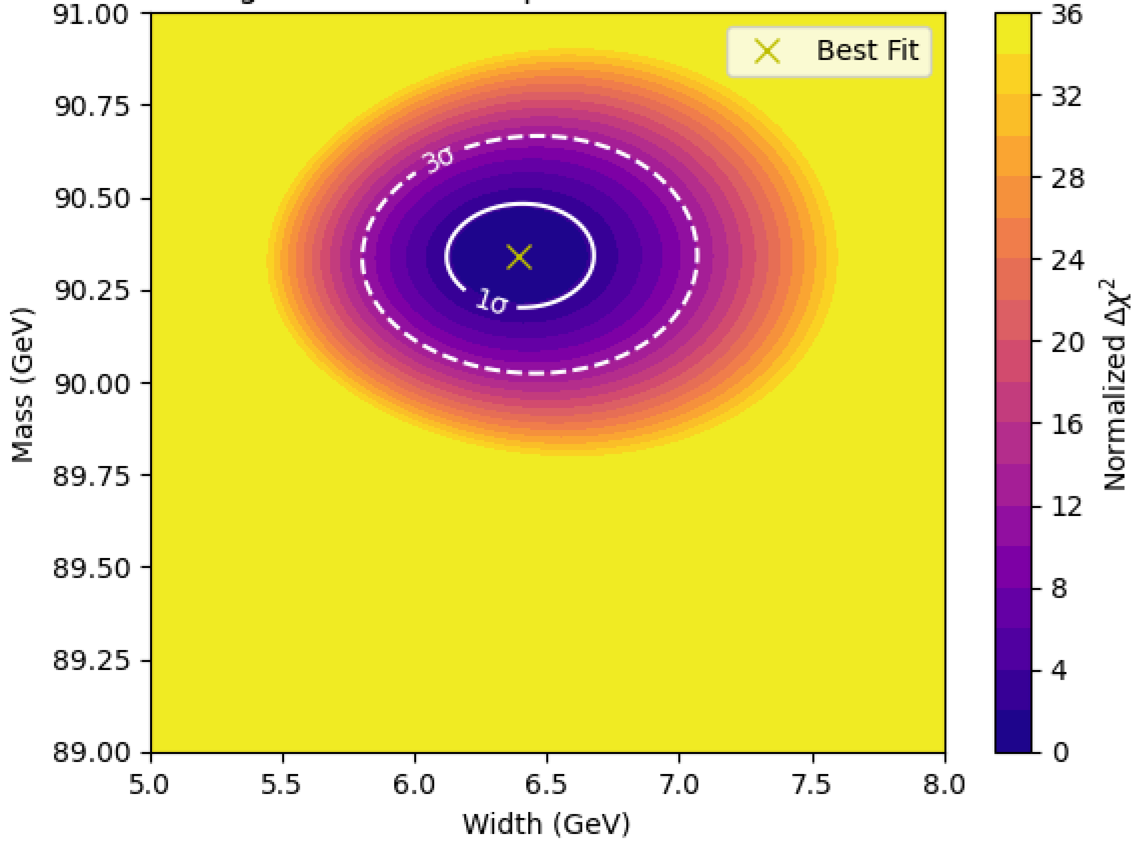
Figure 1: Invariant Mass Distribution



III The 2D Parameter Scan

In Part 3, I performed a 2D chi-square scan of the mass-width parameter space, by calculating the chi-square value for each mass-width pair, using the mass from 89 to 91 GeV and width from 6 to 8 GeV, with 300 bins along each dimension. I then calculated $\Delta\chi^2 = \chi^2 - (\chi_m)^2$, where χ_m is the minimum χ^2 values, which I then clipped at 35 units. I plotted the contour plot of the delta chi-squared values and then drew the contours for the 1 σ and 3 σ away from the best-fit data and plot an X to mark the best fit value of the mass and gamma.

Figure 2: 2D Chi-Square Parameter Scan



IV Discussion and Future Work

The measured Z^0 mass calculated from the Breit-Wigner fit was 90.3 ± 0.1 GeV, while the current PDG accepted values, 91.2 ± 0.0 GeV. The value calculated is significantly close to the PDG value, confirming the data and calculations are representative of the Z^0 boson decay. The curve of fit, and the best-fit mass and gamma values, were confirmed by the reduced chi-square value of approximately 1.0 and a p-value of 0.4, suggesting statistical significance of the values. Additionally, Figure 2 shows how the best-fit value is located within the 1 σ value, providing additional validity for the best-fit values. The main approximation we made to calculate these values is that this is a Poisson counting experiment, limiting the error on the number of events to the square root of the number of events in the bin. Future research could be done using different counting experiment models and using different sets of data from different years to verify the data collected from the 2020 ATLAS open data set.